Retrofit of school ventilation and pupil well-being and performance being and performance – ASHRAE RP1624

Toftum, Jørn; Wargocki, Pawel

Publication date:
2018

Document Version
Peer reviewed version

Retrofit of school ventilation and pupil well-being and performance – ASHRAE RP1624

Jørn Toftum*, Pawel Wargocki

Technical University of Denmark, Lyngby, Denmark
*Corresponding email: jt@byg.dtu.dk

SUMMARY
This intervention study compared five solutions for retrofitting school ventilation. No systematic effect of the system operation mode (on or off) on pupils' wellbeing, symptoms, or performance was observed, but there were significant associations between the performance of some tasks and the classroom CO_2 concentration and temperature.

KEYWORDS
Air quality, temperature, intervention study, children.

1 INTRODUCTION
Environmental conditions in many elementary schools are so inadequate that they are failing to provide a comfortable, healthy and stimulating learning environment. One of the most common problems is inadequate ventilation. To alleviate this, recommendations are needed for different systems that can be retrofitted to improve classroom ventilation and thus indoor environmental quality. The aim of this field intervention study was thus to compare different retrofit solutions to improve classroom ventilation and investigate how they affect pupil's perceptions and performance in a school located in a temperate climate.

2 METHODS
The intervention study was carried out in an elementary school located in a temperate climate north of Copenhagen, Denmark. Three classrooms were retrofitted with four different ventilation solutions: 1) A decentralized, mechanical ventilation system; 2) A system allowing automatic window opening; 3) A system allowing automatic window opening assisted by an exhaust fan; 4) A system allowing automatic window opening supported by heat recovery units. In another classroom that was not retrofitted with a dedicated ventilation system, the intervention was to let teachers and pupils use a device providing visual feedback on the CO_2 concentration in the classroom. The performance of all solutions was compared against a reference classroom in which pupils and teachers manually had to open windows.

During three six-week intervention periods including both heating and non-heating seasons, the performance of all five solutions for improving ventilation was evaluated based on measurement of the conditions in the classrooms, pupil's perceptions of the classroom environment, their acute health symptoms, and their performance of school work. The operation mode of the systems alternated in one or two week periods between ventilation through manually operable windows (off mode) and ventilation by the retrofitted system (on mode). Toftum and Wargocki (2016) describe more carefully the control of the systems and the classroom environmental conditions with systems in on or off mode.

3 RESULTS AND DISCUSSION
The classroom CO_2 concentration was clearly lower during the on than during the off mode periods, but it was not reflected in the pupils' perception of the environment. Also, no clear difference in the intensity of symptoms reported by the pupils was observed. There were some

irregular effects on performance. For example, the speed of the mathematical tasks increased in the classroom with the decentralized mechanical ventilation system and in the room with the CO_2 display unit. The absence of a general relationship between the ventilation retrofit and performance could be due to relatively low CO_2 concentrations when the tests were performed. This is a logical consequence of the retrofitted systems being installed and operated as they would be in any given school subject to a similar retrofit, where no special efforts were made to optimize the systems or achieve well-defined exposures in the classrooms.

Additional analyses were therefore performed to examine the effects of temperature and CO_2 on pupil performance, independently of the systems installed in the classrooms and their operation mode. In this analysis, all data on performance was pooled with CO_2 concentrations and temperatures measured in the classrooms when tests were completed. Table 1 summarizes the results of a linear mixed effects analysis of the association between the classroom CO_2 concentration and temperature and the performance outcomes of the d2 and mathematical tests. The effect of the CO_2 concentration and temperature was not consistent across tests, but the d2 concentration performance, the subtraction speed, and the multiplication speed increased significantly with decreasing CO_2 concentration. The d2 concentration performance and the subtraction speed unexpectedly increased with the temperature, which could be a result of the narrow temperature range that was measured during the lessons when the tests were completed. The error rate did not depend significantly on the CO_2 concentration or the temperature.

Table 1. Results of a linear mixed effects analysis of the association between performance outcomes and the CO_2 concentration and temperature. P-values adjusted for pupil nested within class, for learning, and for individual differences.

Performance metric	Effect at reduced CO_2 / p-value	Effect at reduced temperature / p-value	N
d2 concentration performance	Increase / 0.032	Decrease / 0.041	1402
Subtraction speed	Increase / 0.001	Decrease / 0.001	288
Subtraction errors	0.579	0.947	267
Multiplication speed	Increase / <0.001	0.116	193
Multiplication errors	0.489	0.181	171
Math speed	0.192	0.819	776
Math errors	0.699	0.093	707

4. CONCLUSIONS

All retrofitted systems improved the classroom conditions, although to varying degrees. Alternating the systems between on and off modes affected clearly the classroom CO_2 concentration, in particular during the heating season, but the effect of the control mode on pupils' perceptions and performance was not systematic. However, a significant association was found between pupil performance of the mathematical tests and the classroom CO_2 concentration and temperature.

ACKNOWLEDGEMENT

Financial support for this study was obtained through research project 1624-RP granted by the American Society of Heating, Refrigerating, and Air Conditioning Engineers, ASHRAE.

5. REFERENCES

Toftum, J., Wargocki, P. (2016) Effects on pupil well-being and performance of classroom ventilation retrofits – ASHRAE RP1624. Proc. Of Indoor Air 2016, 3-8 July 2016, Gent, Belgium, paper no. 502.